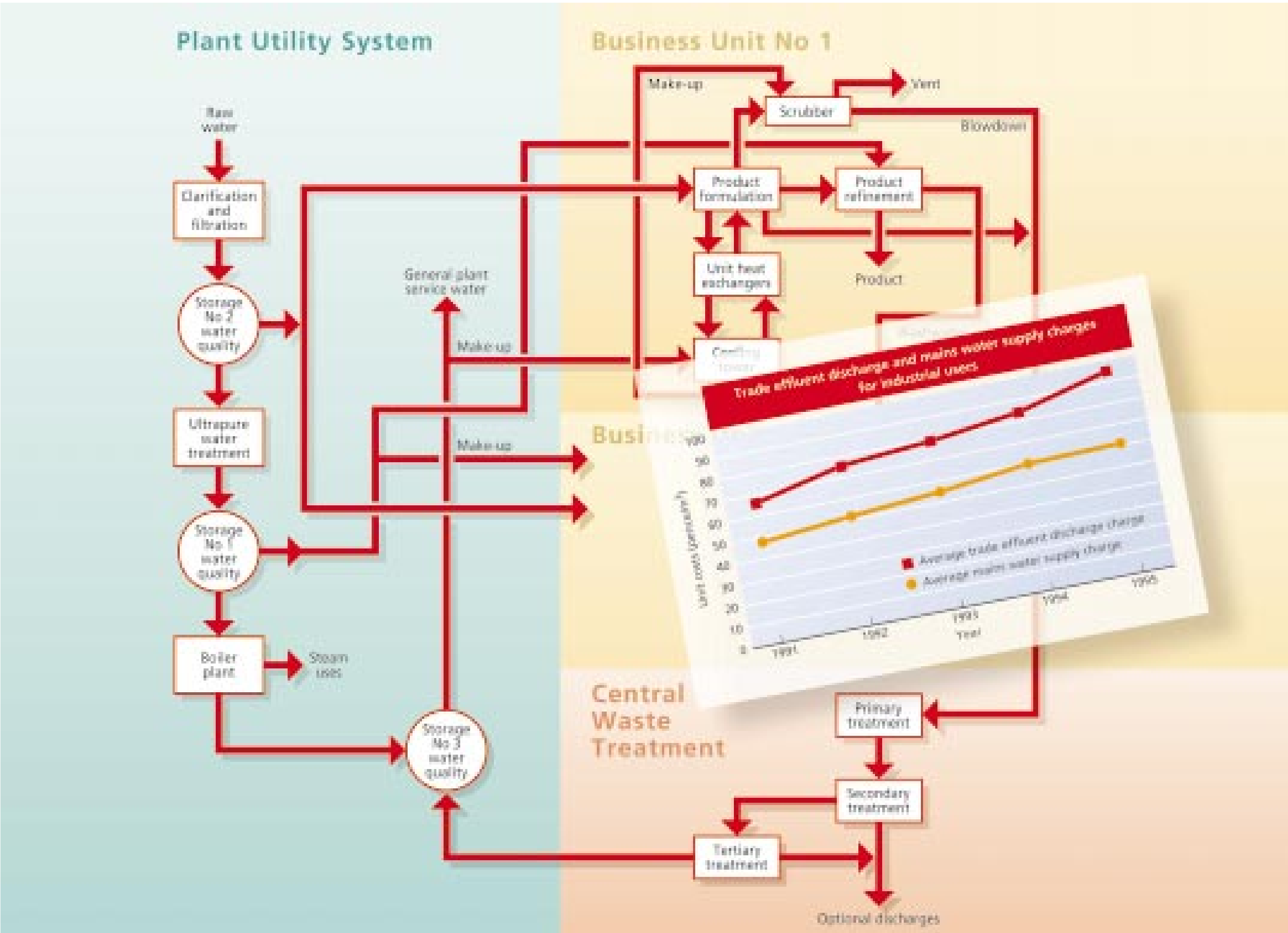
GOOD PRACTICE GUIDE 225

Industrial cooling water systems



ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

GOOD PRACTICE GUIDE 225

INDUSTRIAL COOLING WATER SYSTEMS

This Guide is No. 225 in the Good Practice Guide series and it is intended to provide advice on practical ways of improving the energy efficiency of industrial cooling water systems. The Guide reviews cooling systems in general, and presents a range of energy saving measures covering system operation, maintenance and refurbishment, and design modification, illustrated with case histories to show the potential for energy savings.

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FOREWORD

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

— *New Practice projects:* (light green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— *Future Practice R&D support:* (purple) help to develop tomorrow's energy efficiency good practice measures.

If you would like any further information on this document, or on the Energy Efficiency Best Practice Programme, please contact the Environment and Energy Helpline on 0800 585794. Alternatively, you may contact your local service deliverer – see contact details below.

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1. INTRODUCTION

1.1 Why a Good Practice Guide for Industrial Cooling Water Systems?

UK industry could cut up to £60 million each year from its energy bill for running cooling water systems. Many companies can achieve savings of 10% without major investment, simply by reviewing system operation, maintenance, and design.

This Guide will help you to save energy in cooling water systems by:

- showing you particular areas to focus on;
- providing examples of savings achieved in real installations;
- referring to more detailed information in other Energy Efficiency Best Practice Programme publications, where appropriate.

Fig 1 Cooling tower at Cray Valley Chemicals

1.2 How to Use this Guide

The Guide has four main Sections:

Section 2. Understanding your cooling water system - seven simple steps to help identify opportunities for savings.
Section 3. Effective control - ways to make best use of your existing cooling water system.
Section 4. Maintenance and refurbishment - cost-effective retrofit improvements.
Section 5. System design - strategic considerations when installing or modifying cooling water systems.

The key points are summarised in an Action Checklist in Section 6.

Alternatively, you can access information on the individual components of a cooling water system by reference to Fig 2.

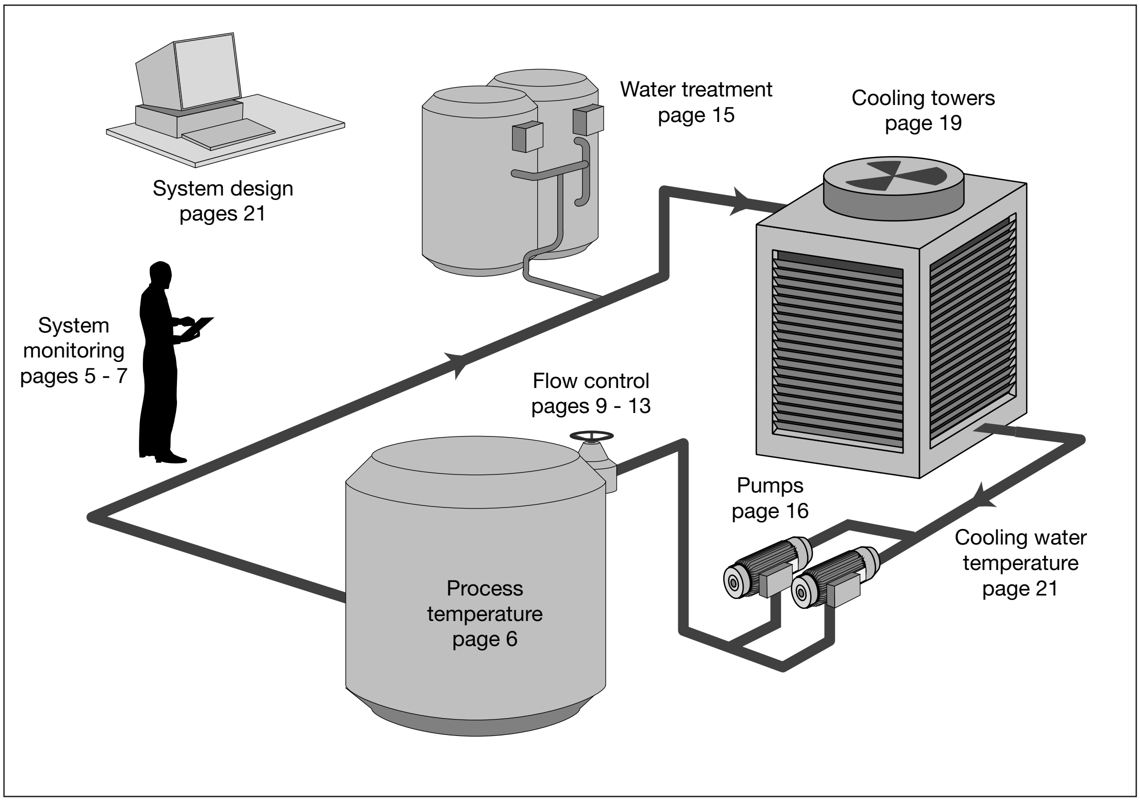


Fig 2 Schematic diagram linking the Guide contents to key components of cooling water systems

Throughout the Guide, reference is made to other Energy Efficiency Best Practice Programme publications which provide a more detailed treatment of the topics covered. These publications can be obtained, free of charge, from ETSU (see rear cover of this Guide).

1.3 Cooling Water Systems in Context

Virtually all industrial companies operate some plant or equipment that requires cooling. This plant may range in size from a single air compressor in a small factory unit, through to the large condensers found in the petrochemical and power generation industries. Wherever there is a need to remove heat, there will be a requirement for a cooling system of some type or other. Typical applications include:

- chemical reactor cooling;
- condensers for distillation columns and evaporators;
- turbine cooling and steam condensing for power generation;
- condensers for refrigeration plant;
- cooling of mechanical plant such as air compressors;
- air-conditioning systems.

The two important properties that characterise the performance of a cooling system are:

- the minimum temperature to which it can cool;
- the maximum rate at which it can extract heat.

The required values for these two properties will influence the type of cooling system used, along with its energy efficiency, size, maintenance requirements and capital cost. Cooling systems therefore, use a variety of 'cold' fluids which contact the material or process, either directly or through a heat exchanger. These can be supplied at ambient temperature or their temperature can be lowered using refrigeration equipment. The characteristics of the main cooling system options are summarised in Table 1.

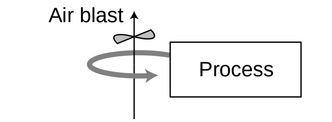
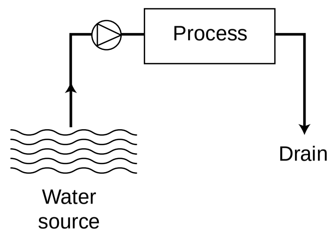
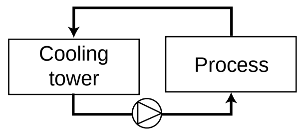
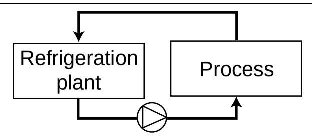
As can be seen, for cooling applications down to approximately 45°C, ambient air can be used. From here, down to around 15°C, cooling water can be used, but to achieve process temperatures much below this will require some form of refrigeration. Historically, the most common means of providing industrial cooling has been via cooling water systems because:

- they operate over a generally useful temperature range;
- large centralised systems are easy to engineer and operate;
- water is intrinsically safe and relatively cheap;
- heat dissipation can be effectively achieved by evaporation (in a cooling tower), allowing the bulk of the water to be re-circulated;
- even when refrigerated systems are used, the heat abstracted must ultimately be dissipated to atmosphere (unless it is recovered into another part of the process), and this frequently involves the use of a final cooling water circuit.

This Guide concentrates on cooling water systems, but much of the information (for example on controlling demand) has relevance to other cooling systems. In addition, there are a number of other Energy Efficiency Best Practice Programme publications covering refrigerated systems. For further details request:

Good Practice Guide 42, *Industrial Refrigeration Plant: Energy Efficient Operation and Maintenance*;
Good Practice Guide 44, *Industrial Refrigeration Plant: Energy Efficient Design*;
Good Practice Guide 59, *Energy Efficient Design and Operation of Refrigeration Compressors*.

Table 1 Principal characteristics of alternative industrial cooling systems

		Schematic diagram	Temperature °C Cooling fluid - inlet to process	Temperature °C Process outlet	Heat removal rate	Capital costs	Maintenance cost	Water and/or treatment costs	Energy use	Comments
Air cooling			10 to 30	>45	low	low to medium	low	N/A	low	Large heat exchanger and ground area/floor space needed - poor performance in summer.
Water cooling	Once through - mains water		Mains water 5 to 10	>15	medium	low	low	high	low	Prohibitively expensive water/effluent costs on all but the very smallest of applications.
Water cooling	Once through - surface water		Surface water 5 to 20	>25	medium	medium	low to medium	low to medium	low to medium	Only possible at sites with plentiful local ground/surface water supply - abstraction and discharge consents needed - relatively high water/effluent costs.
Water cooling	Once through - ground water		Ground water 5 to 10	>15	medium	medium	low to medium	low to medium	low to medium	
Water cooling	Recirculatory cooling tower		Cooling tower 20 to 30	>30	medium	medium to high	medium	medium	medium	Health and safety codes for water treatment (Legionella) - performance reduced in summer.
Refrigerated system			Below zero	Below zero	high	high	high	medium (if water cooled)	high	Specialist use when lower temperatures are required.

2. UNDERSTANDING YOUR COOLING WATER SYSTEM

Many companies pay very little attention to their cooling water systems until there are production problems as a result of inadequate cooling. Oversized systems, and systems run at full capacity regardless of real demand, can result in companies incurring thousands of pounds worth of unnecessary energy, water, and effluent charges each year. To help improve the performance of your cooling water system, work through the following seven steps.

2.1 Make Sure Your Water and Effluent Charges are Correct

Don't pay for services that you are not using.

Check your water and effluent bills carefully to identify:

- billing errors (for example, long periods of estimated readings);
- the basis on which charges are being levied.

Very often, sewerage or trade effluent charges are levied by the water company on the basis that the volume discharged equals the volume of fresh water supplied. This will be a gross over-estimate if quantities of water are disposed of by other routes, for example by incorporation into product or by evaporation from cooling towers, and you will be paying for disposal services that you are not using. Approach your water company to obtain a 'non-return to sewer rebate' for the water disposed of by other means.

Also, keep a regular check on the amount of fresh water being used by your cooling system by installing a meter if none already exists. Regular meter readings will help identify leaks that may otherwise go unnoticed. They will also enable you to negotiate a more accurate non-return to sewer rebate.

A H Marks

AH Marks manufactures specialised organic chemicals. In 1996 the company undertook a site survey and a full mass balance of all water flows. As a result, site consumption was reduced by 70%, representing at least £280,000/year savings in water and effluent charges. This was achieved by repairing faulty valves and an underground leak, and by modifying cooling water systems to reduce losses during the filling and emptying of reactor jackets. Meters were installed, identifying a further 100 tonnes/day of potential savings.

2.2 Find Out How Much Electricity Your Cooling System Uses and How Much This Costs

If you can't measure it, you can't control it.

If your cooling water system is not separately metered, and you don't know how much electricity it is actually consuming, make an initial estimate using whatever load data you have available. For example, you could estimate the annual kWh electricity use and cost for each pump and fan from:

- average kW load (from motor ratings, panel ammeter readings etc.);
- average hours run in a year;
- average site electricity price.

Where this initial estimate of annual electricity cost exceeds £15,000, you should seriously consider installing one or more sub-meters to allow direct measurement of energy usage.

Installing sub-meters can be very cost-effective even for modest systems. Meters cost around £500 each to install and will enable you to rapidly detect, quantify and rectify any deterioration in performance. They will also allow you to observe the effects of operational changes and to confirm the savings obtained from any investment in energy efficiency improvements. Often, one meter is sufficient to measure overall performance, but separate meters on significant equipment can be justified for large systems.

2.3 See Whether or Not Your Cooling Water System is Adequately Controlled

If production output drops, does your cooling water system's electricity and water consumption follow suit?

Take meter readings regularly (e.g. monthly or even weekly) and plot electricity and water consumption against an appropriate indicator of production output to see whether there is a correlation. This simple plot will give you a quick indication of how well your supply of cooling water relates to the production demand. If there is no correlation, this probably indicates that your cooling water system is inadequately controlled.

> For further guidance request Fuel Efficiency Booklet 13, *Waste Avoidance Methods* which gives an introduction to plotting and interpreting simple energy and production data. For a more advanced treatment see Good Practice Guide 31, *Computerised Monitoring and Targeting* and Good Practice Guides 112/125, *Monitoring and Targeting in Medium to Large/Small Manufacturing Sites*.

2.4 Define the Final Temperature Required for Each Process Being Cooled

Do you know what you have to achieve?

For some processes, like vacuum condensation, the final process temperature is critical and hence is likely to be closely defined and controlled. In many other applications, final process temperature will not be critical, provided that it is sufficiently low (for example, to stop a chemical reaction or to enable product handling).

You should aim to define a maximum acceptable final temperature for every process requiring cooling. How closely you approach this value will have a major impact on energy costs. If the final temperature requirements are not accurately known or your cooling water system is not optimally controlled, you will have to operate with a large safety margin to ensure acceptable production.

2.5 Compare the Required Final Process Temperatures with Those Actually Being Achieved

Over-cooling is a major cause of energy wastage in cooling water systems.

Once target temperatures have been defined, it will be necessary to monitor the actual temperatures achieved in normal running to see how closely they approach the optimum. In many cases, temperature measurement is a normal part of process control. Where this is not the case, installing appropriate measuring devices is relatively inexpensive, the cost of a thermocouple and data recorder typically being only a few hundred pounds.

Cooling any process or piece of equipment below the temperature actually required will place an unnecessary thermal load on the cooling water system. This will lead to increased electricity and water usage. You should, therefore, review the operation of all of your cooling water users to identify any overcooling. Where overcooling is found, it should be corrected either by changes to operating procedures or by the installation of appropriate automatic controls (see Section 3).

2.6 Select the Correct Cooling Water Temperature

Incorrect water temperature will prejudice energy efficiency.

The correct choice of cooling water temperature will be influenced by a number of factors including:

- the required final process temperature;
- the performance of the process to cooling water heat exchanger;
- the cost of lowering the supply temperature of the cooling water;
- the pumping costs associated with circulating the cooling water.

The difference between the required final process temperature and the cooling water supply temperature is called the **temperature approach.**

The majority of cooling water systems are designed with a temperature approach of between 10 - 20°C, as this represents a practical economic balance. A larger temperature approach (i.e. lower water temperature) can only be achieved by installing additional refrigeration or cooling tower capacity with a corresponding increase in capital and running costs. Conversely, a smaller temperature approach (i.e. higher water temperature) will necessitate that a larger process/cooling water heat exchanger is installed to achieve the required rate of cooling. Higher water circulation rates will also be required, resulting in a need for bigger pumps and increased electricity consumption.

The most economic operating regime for your cooling water system is likely to be with a temperature approach within the design range of 10 - 20°C. In practice, however, many systems operate wastefully at values below 5°C. Review your process requirements and define a target cooling water temperature for your system.

2.7 Review Your Cooling Water Flow Rates

Pumping is likely to be the major energy user on your cooling water system.

Pumping more water than necessary will waste electricity and may increase pump maintenance costs. Excessive pumping can occur when:

- abnormally high flow rates are used to provide cooling;
- cooling water flows are left running when not required.

In the same way that temperature approach can provide a useful indication of correct cooling water supply temperature, the cooling water **temperature rise** can be used as an approximate benchmark for water flow rates. In general terms, a cooling water temperature rise of less than 5°C is a probable indication of excessive water flow. This may cause over-cooling of the process (see Section 2.5) or, if not, may point to an insufficient temperature approach due to the cooling water supply being too warm (see Section 2.6). In either case, excessive water flow rates will lead to increased electrical consumption by the circulating pumps.

Checking that cooling water flows are turned off when not required is an obvious point, but one that is often overlooked.

A CAUTIONARY NOTE!

The rules of thumb presented in this Guide are not definitive, and only give an indication of where opportunities for improvements may be found. In practice, the scope for altering your system operation may be limited by its design - pump size, cooling tower capacity, etc.

Furthermore, it is important that the energy efficiency of the process being cooled is not prejudiced by ‘improvements’ to the cooling water system. For example, the thermodynamic efficiency of refrigeration compressors improves markedly with decreasing condensing pressure. This pressure can be reduced by using colder cooling water but this may require that cooling tower fans are run continuously - causing them to use more electricity. As usual, there is a balance to be struck, but in this case the energy benefits of improving compressor efficiency are likely to far outweigh the associated additional fan power.

3. EFFECTIVE CONTROL

The steps presented in Section 2 will have highlighted any requirements for improved control within your cooling water system. These may relate to process temperature, cooling water temperature or cooling water flow. Furthermore, the type of control required can be characterised by its location, namely:

- point-of-use control (e.g. the local control of a process temperature);
- system control (e.g. the control of cooling water temperature at a central cooling tower).

As a general principle, it is best to address point-of-use control issues first. This will ensure that subsequent decisions on improved system control will be based on an optimised cooling load requirement. This may allow, for example, additional circulating pumps to be isolated at times of low cooling demand.

It is essential to recognise, however, the critical importance of effective system control. Without it, time and money spent improving point-of-use control will be largely wasted. For example, you may decide to install local solenoid valves to automatically turn off cooling water flows to plant when not required. The savings resulting from this measure will be marginal unless system controls are in place to reduce pumping capacity in line with the reduced demand.

3.1 Point-of-use Control

Central cooling systems often serve a number of disparate processes and it is possible for supplies to be left running to plant that is not actually in use. Although this will not impose a process cooling load on the system, energy will be wasted due to unnecessary pumping and as a result of the heat gained by the cooling water from its surroundings as it flows around the pipework.

In many smaller installations, cooling water flows are controlled manually and if this approach is to be continued, the plant operators' awareness and understanding of efficiency issues may need to be improved. Training initiatives to provide suitable education and encouragement are usually very cost-effective.

> Further information can be found in:
>
> Good Practice Guide 84, *Managing and Motivating Staff to Save Energy*;
> Good Practice Guide 85, *Energy Management Training*;
> Good Practice Case Study 265, *Energy Savings in a Small Company*.

In many situations, more reliable control can be achieved by the installation of low cost automatic controls to isolate or regulate cooling water flow. These could comprise:

- solenoid operated isolation valves, which are electrically interlocked to the process or plant being cooled;
- flow regulating valves, which act to maintain either a set process or cooling water discharge temperature.

Glaxo Wellcome

The cold water supply to a number of batch reactors at Glaxo Wellcome's Dartford plant used to be manually controlled. In practice, this often meant that water was left running continuously at full bore which, in turn, led to irregular cooling loads and more pumps being run than were strictly necessary. In addition, it caused high back pressure in the return pipework which the operators alleviated by bleeding cooling water to drain.

Automatic thermostatic controls were installed on each reactor, which, along with a series of other minor changes, have reduced the make-up water demand of the cooling system by 10 m^3/hour and have saved 115 kW of pumping power.

The controls cost £12,600 to install and have given savings worth £31,000/year, representing a payback period of five months.

3.2 System Controls - Circulating Pumps

To get maximum energy savings, the central supply of cooling water must be effectively controlled to match local demand patterns. Controls such as thermostatic valves will reduce local flow demand, but the potential benefits can only be fully exploited where the central flow supply changes accordingly. This will require an appropriate pump control regime, which can be either manual or automatic. Two options that will waste energy are a cooling water ring main run at constant flow and the use of valves to throttle the pumps' output.

A complete treatment of most aspects of energy efficiency in pumps is given in Good Practice Guide 170, *Water Pumping in the Steel Industry*.

The key points relating to control are summarised in the following paragraphs.

There are several options for controlling pumps and a picture of the actual flow demand pattern should first be constructed to determine which is best suited to any particular operation. This can be carried out with minimum effort over a period of weeks by simple observation or by taking measurements of cooling water return temperature. This will identify periods of low temperature rise corresponding to low demand. The measurements may highlight, for example, any set times of the day or week when demand is always reduced and thus indicate the potential for simple time-switch control.

On/Off Control

In batch processing on small sites, there can be significant periods when there is no cooling demand. In this situation, the whole cooling water pumping system could be switched off manually, via a time-switch or through a link to the process control systems. There are some limitations, however, including possible damage to the pumps' electric motors if they are switched too frequently and the time needed for the system to recover to full capacity after an extended switch-off period. The fitting of a 'soft-start' system will help eliminate motor damage due to frequent starting.

Step Control: Multiple Pumps

Many cooling water systems have a number of pumps installed in parallel. This gives the opportunity to control the flow in discrete steps by switching one or more of the pumps to match demand. In the simplest systems, this can be done manually or by using a time-switch if appropriate. For more intelligent control, a microprocessor based system which responds to changes in cooling water differential temperature or pressure can be installed at a modest cost. This will provide the significant benefit that changes in the demand for cooling water will be

immediately responded to, even if they are unscheduled. Once again, however, it is important to ensure that the pumps' motors are not switched too frequently and this ultimately limits the responsiveness of step control. It is also necessary to hydraulically isolate any off-line pumps to prevent water short-circuiting back through them. Automatic hydraulic isolation can be provided using non-return valves, but these should be checked annually to ensure reliable operation.

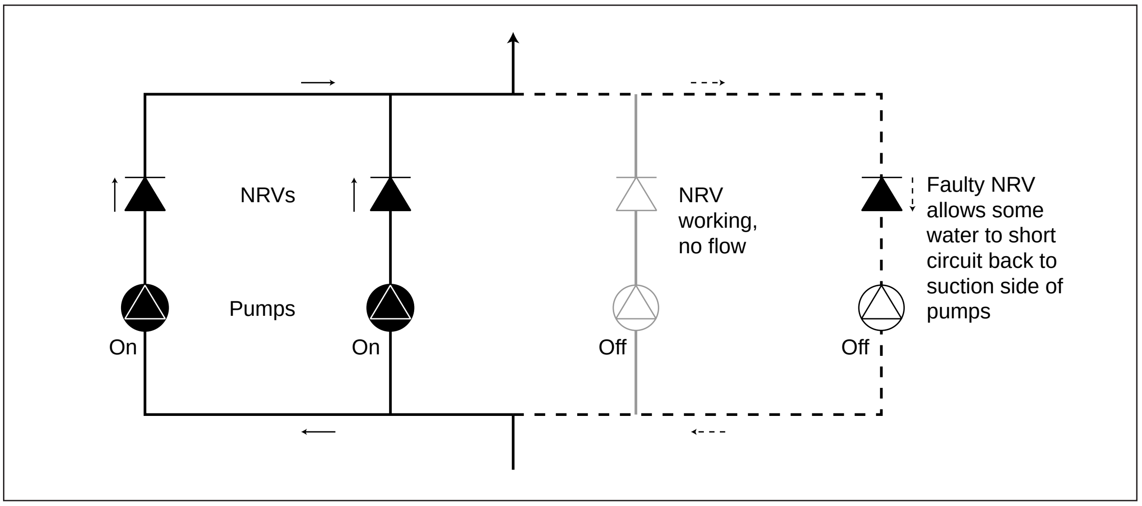


Fig 3 The importance of non-return valves (NRVs) in multiple pump installations

Step Control: Single Pumps

If a pump motor burns out, consideration should be given to replacing it with a multiple speed motor, rather than rewinding it or buying a straight replacement. Multiple speed motors allow step control to be applied to individual pumps and the resulting energy savings can make them a cost-effective replacement option even for smaller systems. On larger systems, they can be economically viable even as a retrofit.

Variable Speed Control

Electronic Variable Speed Drives (VSDs) can progressively vary pump speed to precisely match the delivered flow to the prevailing demand. This option produces the largest energy savings and the latest generation of VSDs have proved themselves to be both reliable and cost-effective.

There are a range of Energy Efficient Best Practice Programme publications covering various aspects of energy efficiency in pumps, electric motors and motor controls.

Good Practice Case Study 89

Manchester Airport installed Variable Speed Drives (VSDs) on the chilled water pumps which serve their ventilation systems' air handling units. The VSDs vary the water flow in accordance with cooling requirements and have replaced the traditional control method of using three-port valves to divert the full flow away from each air handling unit.

The installation cost £49,600 and has provided an annual saving of £26,800, resulting in a simple payback period of 1.9 years.

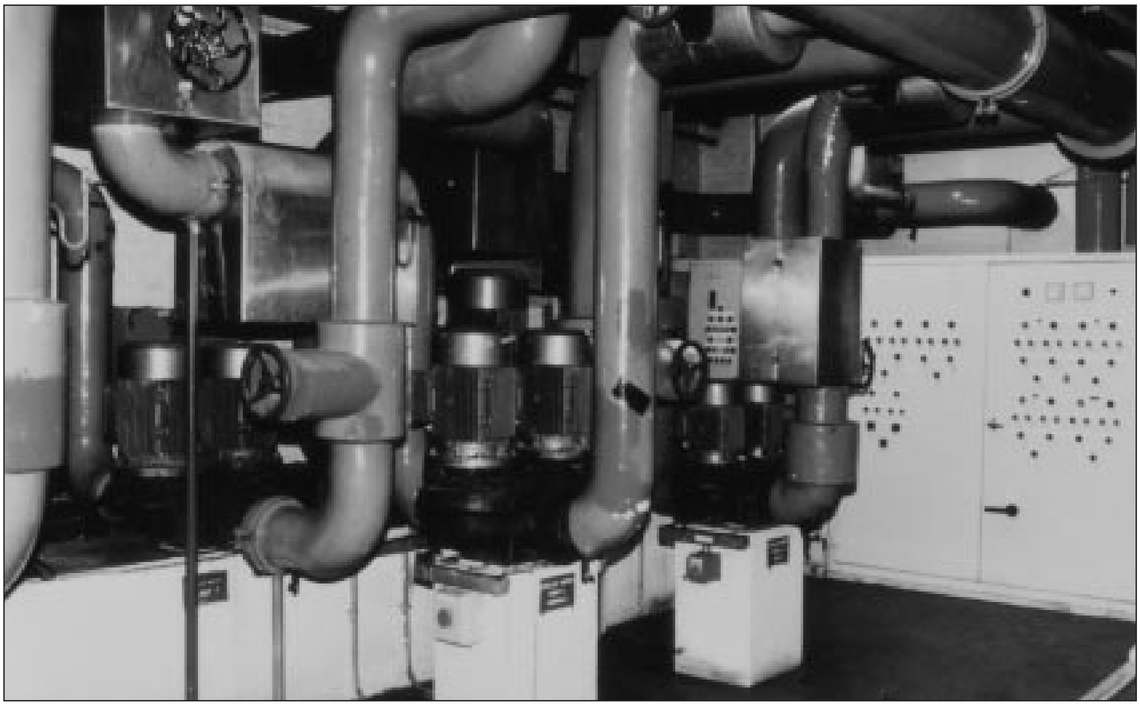


Fig 4 VSDs on chilled water pumps at Manchester Airport

3.3 System Controls - Cooling Towers

Cooling towers are generally designed for the maximum summer wet bulb temperature, and can be significantly larger than needed for most of the year. In mechanical draught towers, fans can be switched off or slowed down for significant periods with no adverse effects. A supply water temperature sensor can be used to control fans by a number of methods.

On/Off Control

This uses a simple thermostat to switch the fans. The differential must be set wide enough to avoid frequent switching as this could damage fan motors. Appropriate advice should be sought from the motor manufacturer. Alternatively, consider installing a 'soft-start' system to protect the motor.

Step Control

This involves fitting dual-speed or multi-speed motors to the fans with each speed being selected by a step controller in response to cooling water temperature. Dual-speed motors, for example, can provide 0%, 50% and 100% of the full fan output. Multi-speed motors are only likely to be a cost-effective retrofit for large individual towers, but step control can also be applied to multiple tower installations with single speed fans. Multiple speed motors can be a cost-effective alternative to rewinding or the straight replacement of burnt out motors.

Good Practice Case Study 265

Hampshire Chemical Ltd fitted a simple step controller to three cooling tower fans, linked to a temperature sensor in the supply water. The installation cost was £4,600, and the controller is giving annual electricity savings of £3,050.

Variable Speed Control

VSDs can progressively vary fan speed to closely control the cooling water temperature. This option produces the largest energy savings and the latest generation of VSDs have shown themselves to be both reliable and cost-effective.

Good Practice Case Study 270

In 1993, Cyanamid UK installed a variable speed drive on an existing 30 kW fan motor on one of its cooling towers, linked to a temperature control signal from the water leaving the tower. The installation cost £5,400, and gave electricity savings worth £6,260 over the twelve month period March 1993 to February 1994. In addition, the closer temperature control has led to reductions in water, effluent and chemical costs.

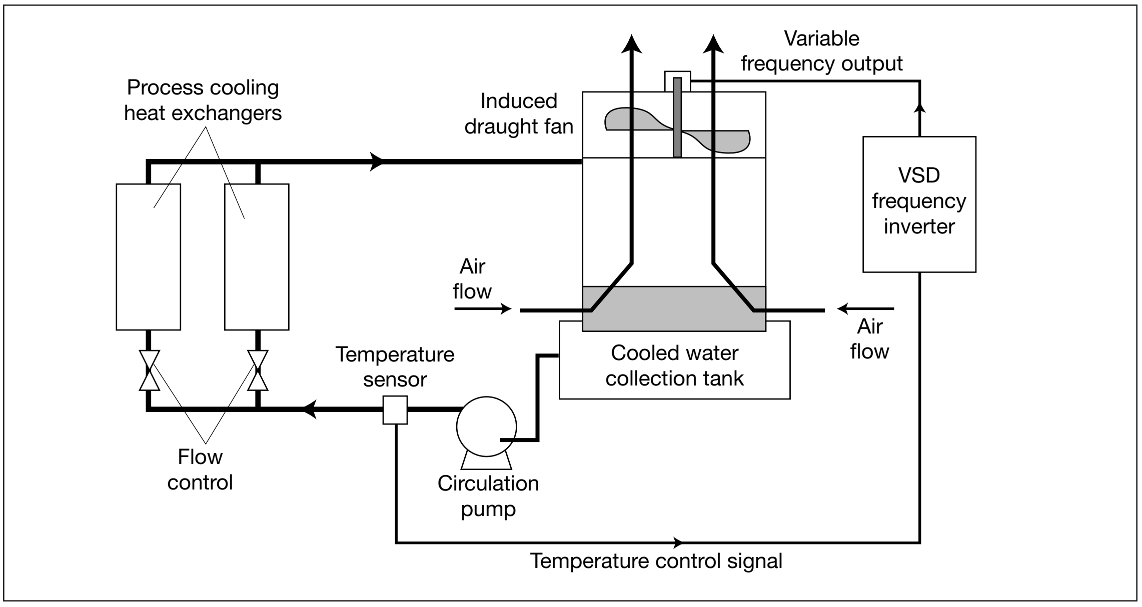


Fig 5 Flow diagram of process at Cyanamid UK

Detailed information can be obtained by requesting:

Good Practice Guide 2, *Energy Efficient Motors & Drives*.

4. MAINTENANCE AND REFURBISHMENT

Appropriate maintenance is vital if cooling water systems are to operate at peak efficiency. Maintenance should ideally be planned as a preventative measure, rather than being an ad-hoc activity when plant fails. Gradual deterioration in equipment may not be noticed if it does not affect production, but could be costing thousands of pounds in wasted energy.

> Further details can be obtained by requesting:
>
> Good Practice Guide 217, *Cutting Energy Losses through Totally Productive Operations* which gives an introduction to, and overview of, planned maintenance systems.

This section summarises some of the main issues to consider in maintaining and refurbishing your system, split down into four main areas:

- pipework and controls;
- water treatment;
- pumps;
- cooling towers.

4.1 Pipework and Controls

The general condition of distribution system pipework and related ancillaries can waste energy in a number of ways:

- **Leaks.** Although the total water flow from leaks may not be great, make-up water supply, treatment, pumping, and cooling costs are still incurred. In addition, leaks occurring under insulation may not be noticed immediately and waterlogged insulation is very inefficient. Internal leaks into the process through corroded heat exchanger tubes are also difficult to identify unless they are actively sought. Regular monitoring of make-up water use, as advocated in Section 2, will help identify the presence of both external and internal leaks.

- **Poor (or no) insulation on pipes and valves.** This will cause unnecessary warming of cooling water as it circulates. It may also increase the risk of freezing in severe weather. The condition of insulation should be checked regularly (particularly for waterlogging), and consideration given to replacing it with a thicker, modular system. Cost-effectiveness will depend upon the cooling water temperature.

> For further details request:
>
> Fuel Efficiency Booklet 19, *Process Plant Insulation and Fuel Efficiency* which gives a good introduction.

- **Scale formation on pipes and heat transfer surfaces.** This causes increased resistance to flow and poor heat transfer. The reactive approach to handling scale formation is routine inspection and cleaning. An alternative and complementary approach is to reduce the rate of scale formation by appropriate water treatment.

- **Sensors drifting and control valves sticking.** This will cause control to become inaccurate and operation to become sub-optimal. Routine checking of sensor calibration and of actuator operation should be part of all maintenance strategies. Check all valves, including non-return valves, to ensure they close off properly.

4.2 Water Treatment

Water treatment can play an important part in preventing corrosion and fouling and in reducing maintenance requirements. However, the main consideration in designing a treatment system is usually the prevention of micro-biological contamination, such as the Legionnella Pneumophilla bacteria (the cause of legionnaire's disease). This is particularly true for cooling tower systems.

Detailed recommendations are given in the following guidance documents:

Health & Safety Executive Guidance Note HS(G)70;
TM13 - Chartered Institute of Building Services Engineers Technical Memorandum;
Health & Safety Commission Approved Code of Practice.

Water treatment can typically involve:

- filtering to remove suspended solids;
- ion exchange to remove dissolved ions;
- the addition of specialised water treatment chemicals;
- the 'blowdown' of a proportion of the volume of water in recirculating systems (and make-up with fresh water), to prevent the build-up of suspended and dissolved solids.

In some specialised applications, such as food and drink and pharmaceuticals, water systems that might come into contact with the product need to be extremely pure. In these cases, water treatment can also involve distillation, and the periodic raising of water temperatures to close to boiling point for biological sterilisation.

The water treatment needed will depend on the cooling water system application and on the properties of the make-up water. Treatment regimes should be reviewed to take into account maintenance and energy efficiency as well as health and safety. There may be particular requirements for new systems or existing systems which are being returned to service after a period of inactivity. Specialist advice and training is available from water treatment companies. This will help you choose the right treatment regime and to operate it correctly. Do not neglect the control of blowdown from evaporative cooling towers as too little will cause fouling of heat transfer surfaces, while too much will waste valuable water and treatment chemicals. There are parallels with the effective management of the water treatment regimes used for steam boiler plant.

Good Practice Case Study 234

In 1990, Holliday Dyes and Chemicals Ltd in Huddersfield undertook a programme to train its boilerhouse operators in efficient boiler operation. This included an on-site course in feedwater treatment in association with the treatment chemical supplier. Shift Engineers now carry out a daily water analysis, including measurements of:

- conductivity;
- alkalinity;
- sulphite levels;
- total dissolved solids;
- feedwater temperature (to avoid oxygen pitting).

Reduced blowdown rates and water and treatment chemical costs contributed to savings of £12,000/year, in addition to overall boilerhouse energy savings of £100,000/year through better monitoring and operation as a result of better training.

Fig 6 Water treatment plant at Holliday Dyes and Chemicals Ltd

4.3 Pumps

> Good Practice Guide 170, *Water Pumping in the Steel Industry* gives a complete treatment of most aspects of energy efficiency in pumps.

The key points relating to maintenance are summarised in the following paragraphs.

General Maintenance

The wear of pump internals should be closely monitored as the reduction in efficiency on an unmaintained pump could be as high as 12%. Regular routine maintenance (i.e. replacement of neck ring and impeller) is important.

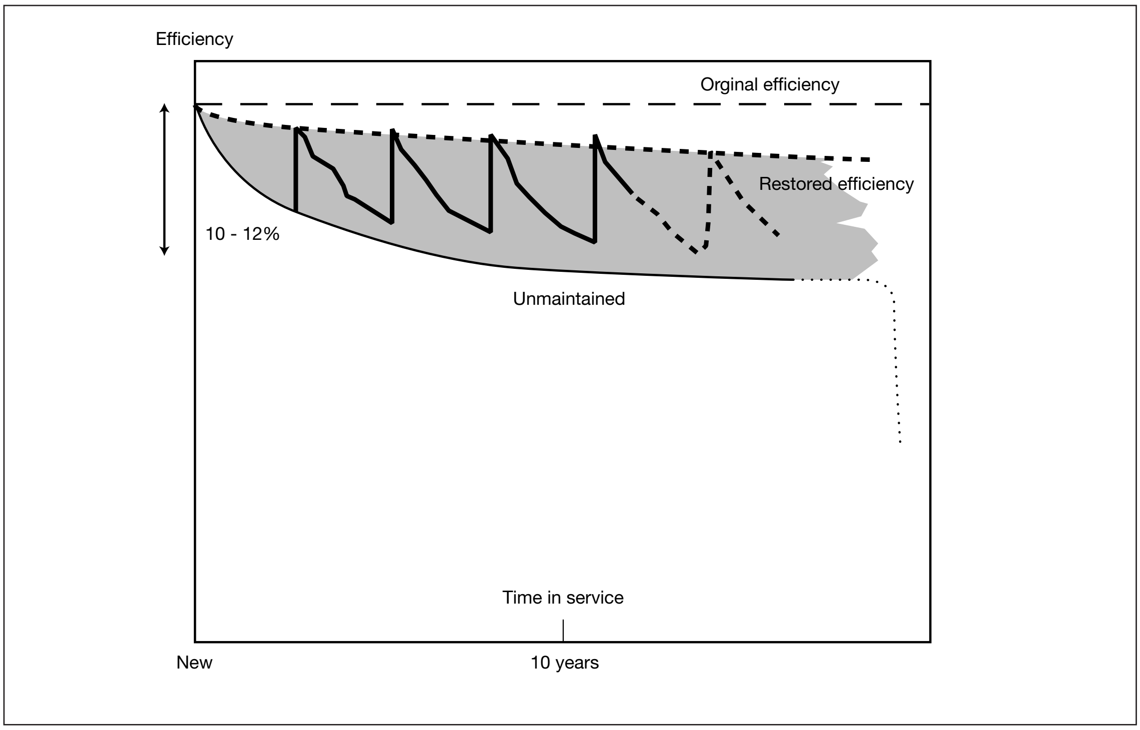


Fig 7 The effect of pump maintenance on efficiency

Filters should be used on pump inlets where appropriate. This will reduce the attrition and wear on the internals due to solids in the water, thereby minimising the amount of maintenance required. Filters should be cleaned regularly to prevent flow restrictions arising that can create adverse effects such as cavitation. In general, a good water treatment regime is an important factor in prolonging operational efficiency.

Measuring Pump Efficiency

Periodic inspection of pump internals can be supplemented by regular non-invasive measurements of the efficiency of larger water pumps. These techniques aid the review of a pump's condition and the quick identification of any deterioration in performance. Corrective action can then be carried out before the drop in efficiency costs too much.

Direct thermodynamic measurement of pump efficiency

In the past, measuring pump efficiency in normal service was difficult and time consuming. Recently developed thermodynamic techniques allow non-invasive measurements and accurate calculation of a pump's efficiency. Readings from sophisticated temperature probes, which are accurate to a few milli-degrees, are used to measure the wasted energy (i.e. that which is converted into heat rather than water flow or pressure), from which the pump efficiency can be derived. Portable devices using this principle make such measurements relatively easy.

Refurbishment - Pump and Motor Sizing

When pumps or motors fail, options include:

- continuing use by repair or rewinding;
- replacement with a similar pump/motor, from existing spares stock or from new;
- critically reviewing the size of the failed pump/motor and replacing it with a more efficient unit if possible.

The first two options are the most common in practice. However, the third option needs only a little extra planning and can result in higher long-term savings where the failed pump/motor is found to have been significantly oversized.

Pumps and their motors are often oversized because of design safety margins or as a result of changes in operation over time. Oversized pumps and motors:

- have a higher initial capital cost;
- do not operate at peak electrical efficiency (particularly if their loading falls below 50%);
- often need to be throttled to match the required flow rates, wasting more energy.

The problem of oversized pumps can sometimes be cost-effectively reduced by refitting a smaller pump impeller or trimming an existing impeller. It may then be appropriate to fit a smaller electric motor to yield further efficiency benefits.

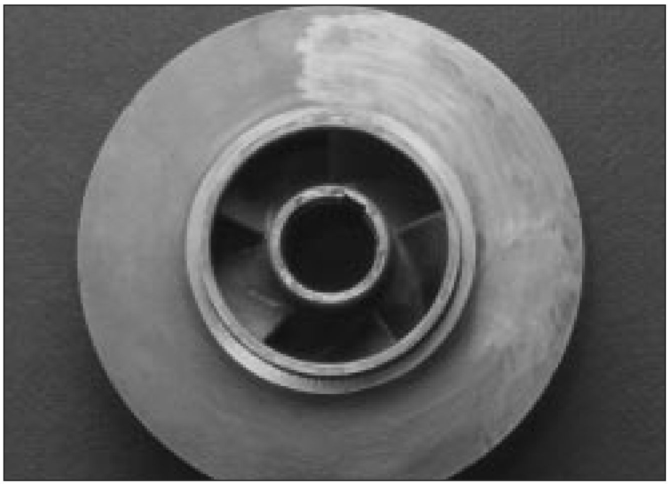


Fig 8 Trimmed pump impeller from Salt Union

Salt Union Ltd

In 1993, Salt Union Ltd modified a pump on their six-effect brine evaporator by trimming the impeller to reduce its diameter from 320 mm to 280 mm (in consultation with the pump manufacturer). For a cost of only £260, this reduced electricity costs by £8,900/year and maintenance and repair costs by £3,000/year.

Refurbishment - High-efficiency Electric Motors

The purchase of new or replacement electric motors also offers an opportunity to select high-efficiency types to reduce running costs. The electricity used by a motor in its lifetime can cost up to 100 times its initial purchase cost. Genuine high-efficiency motors typically show electricity savings of 2 to 3% compared to standard motors and may cost only a little more. These efficiency gains result from the use of higher specification materials and design. Replacing a burnt-out motor with a genuine high-efficiency alternative will often be a more cost-effective long-term option than rewinding or the use of a cheaper replacement. Where large standard motors run almost continuously, consideration should be given to replacing them even before they fail because of the cost savings that will result. Ironically though, motors over 30 years old may already be ‘high-efficiency’ because of the larger amounts of copper and steel used in their construction compared to more recent standard motors.

For more details on higher efficiency electric motors refer to Good Practice Guide 2, *Energy Efficiency in Electric Motors and Drives* and Future Practice Profile 50, *Higher Efficiency Induction Motors*.

Refurbishment - Pump Coatings

Specialist coatings can be applied to the internal surfaces of a pump casing and these will:

- provide additional corrosion resistance;
- reduce frictional/turbulent losses and increase energy efficiency;
- prolong pump life and performance.

These coatings are normally based on polymers or on glass flake, and can be applied to new pumps or retrofitted to existing pumps. The main uses of these coatings are to:

- **Rebuild contours.** Glass flake based coatings can be used as a retrofit to rebuild the contours of worn pumps, returning them to their original operating condition.

- **Reduce friction.** Low friction coatings applied to the body of the pump provide an extremely smooth surface, reducing frictional losses compared to the standard internal finish. Efficiency can increase by between 2 and 8%, amounting to significant savings on large pumps operating for long periods of time.

For many large cooling water pumps, particularly in the petrochemical and power generation industries, applying pump coatings can show an attractive payback especially when all benefits are considered. These include a significant extension to the working life for the pumps as well as energy cost savings.

Case History

Pump coatings have been used by the water industry for several years and extensive field trails have been undertaken to confirm their efficacy. In 1986, direct thermodynamic tests revealed that three Sulzer BPK50 pumps installed at a pumping station were severely worn, with an operating efficiency of only 77%. The pumps were, therefore, subjected to a conventional refurbishment which raised their efficiency to 80%. The refurbished pumps were then treated with a low friction internal coating which further increased their efficiency to over 84%. The cost of refurbishing and coating the three pumps was £17,000. Annual electricity savings worth £17,000 resulted from the improved efficiency, giving a simple payback period of just one year.

4.4 Cooling Towers

Maintenance - Sump Heaters

Many cooling towers are fitted with electric sump heaters to prevent freezing in cold weather. As a minimum, the heaters and thermostat controls should be checked annually for calibration and correct operation. This will ensure that protection is available when needed and yet prevent wasteful operation during milder weather.

Maintenance - Fans

Cooling tower fans should be checked for worn bearings (which can sometimes be detected simply by listening for squealing or rumbling), bent fan blades, and blocked filters, if fitted. Fan motors should be checked regularly as part of planned preventative maintenance to identify worn bearings and burnt out or short-circuited windings. Where fan controls are fitted, the controller and sensors should be checked to ensure that they are operating correctly and are in calibration.

Maintenance - Packing Material, Spray Nozzles, and Re-distribution Decks

The function of all of these items is to ensure a well dispersed, even spray of warm water down the tower in good contact with an even flow of cooling air up the tower. While the tower is running, a simple visual inspection may sometimes reveal uneven water and air flow for further attention. Checks for corrosion and general damage to components should be carried out during downtime, together with checks for scaling, blockages and general fouling.

Refurbishment - Tower Location and Surroundings

Wind can have a strong effect on the performance of natural draught cooling towers and can also affect forced draught towers. Low to moderate wind speeds can degrade performance by disturbing inlet airflow, or by causing warm, moist discharge air from the tower exhaust to be re-entrained at the inlet. High wind speeds can actually boost performance through enhanced airflow due to suction effects. Cooling towers should ideally be located away from any neighbouring tall structures, which may impede the free flow of air into or away from the tower. Baffles can be used to shield towers from wind effects, while ducting can be used to direct air flows around obstructions.

Refurbishment - Packing Material

Where traditional wooden slat type packing is in place, consideration should be given to replacing this with high efficiency plastic cellular packing. This can increase operating efficiency by up to 50%, while improving water distribution within the tower. This in turn gives greater potential cooling duty. Plastic packing can have better aerodynamic properties, but is generally more prone to clogging or fouling with silt and biological organisms. Type selection is crucial and is generally a compromise between good performance and the fouling behaviour in the particular site conditions. The mechanical stability of plastic packing materials must also be considered if high return water temperatures are a possibility.

Refurbishment - Mist Eliminators

In some cases, replacing existing mist eliminators can reduce the amount of water lost from the tower, therefore providing modest savings in pumping energy and in the cost of make-up water and chemical treatment.

Refurbishment - Spray Nozzles or Re-distribution Decks

Replacing existing items with newer designs can improve the dispersion and evenness of distribution of warm water returning from the process at the top of the tower. This increases the amount of heat which can be extracted, thereby improving the overall performance of the tower.

5. SYSTEM DESIGN

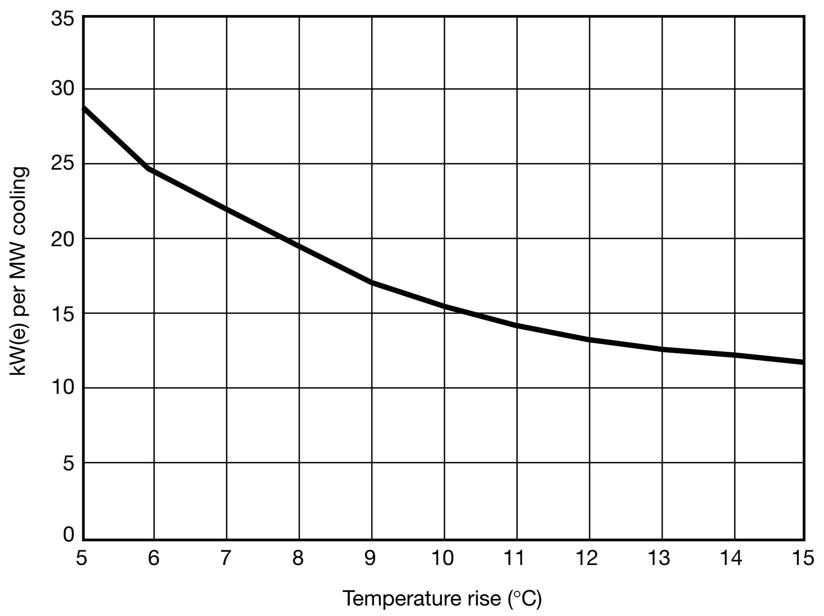
System design offers many opportunities for efficiency improvements.

5.1 Minimising the Cooling Demand of a Process

Target process output temperature should be reviewed for each main product and process stream. Factors which limit the maximum allowable value should also be identified (these can include: stopping a chemical reaction; preventing products from degrading, decomposing or evaporating out of solution; and temperature limit for the next processing or handling stage). Consideration can then be given to modifying processes or installing additional plant to increase the allowable final temperature.

5.2 Design for the Maximum Acceptable Cooling Water Temperature Rise Across the Process

Fig 9 illustrates the strong dependence of energy consumption in pumping on the design temperature rise of the cooling water system. A cooling water temperature rise across the process of 5°C needs approximately twice as much pumping power as a temperature rise of 15°C. Designing for the maximum temperature rise will minimise the size and capital cost of the pumps as well as the ongoing pumping energy costs.



(Based on 5 Bar pump head)

Fig 9 Effect of cooling water temperature rise on pump power demand

The main components of a cooling water system are:

- the refrigeration system (or cooling tower);
- the cooling water circulation system;
- the cooling water/process heat exchanger.

These should be designed to have a matched capacity to serve the requirements of the process for cooling. If the heat exchanger contacting the process is undersized for the duty, then the circulation system usually has to run at a higher flow, wasting pump energy, and the refrigeration

system may have to deliver cooling water at a lower temperature, again wasting energy. The extra capital cost of specifying a larger heat exchanger at the design stage can be offset by a reduction in the size and cost of pumps and refrigeration plant, and will give ongoing energy cost savings in operation.

The optimum blend of capital and operating expenditure for the site over the lifetime of the plant can then be selected, rather than opting for the minimum initial outlay which would be less cost-effective in the long run.

Good Practice Guide 69, *Investment Appraisal for Industrial Energy Efficiency* provides an introduction to lifetime costing of projects for engineers.

Detailed treatments of cooling water system design can be found in many chemical engineering textbooks, notably *Perry's Chemical Engineers' Handbook* by Perry and Green, McGraw-Hill ISBN 0 07 049841 5.

5.3 Localising Cooling Water Supply

Where processes require similar temperature cooling water, but cooler water is needed in a few cases, then zoning the cooling water system and providing additional local cooling only where and when it is needed should be considered. An alternative possibility would be to consider using direct air cooling for the higher temperature processes, and designing a smaller cooling water system to cater for the others.

5.4 Integrate Heat Recovery and Processes (Pinch Technology)

There may be opportunities to usefully recover the heat abstracted by a cooling water system by transferring it to lower temperature applications elsewhere on site. 'Process Integration' or 'Pinch' is a proven methodology for identifying and quantifying heat recovery opportunities, even in complex multi-stage operations. Pinch technology can be used for new plant designs and also for exploring retrofits or modifications to optimise existing processes.

For further reading, look at *A Users' Guide to Process Integration* IChemE, ISBN 0 85295 343 7 and Good Practice Case Study 355, *The Use of Pinch Technology in a Food Processing Factory*.

Good Practice Case Study 355

In 1990, Van den Bergh Oils used Pinch technology to identify the most energy-efficient design for a new edible oil refinery. The technique allowed the refinery's many batch and continuous processes to be effectively integrated via a 'utility water' system which transfers heat between hot and cold streams.

The initial Pinch study cost £30,000, whilst the implementation of the recommendations involved a further cost of £2.06 million. This reduced steam and cooling water costs by over £710,000/year, giving an overall payback of under three years.

5.5 Pipework Design

Cooling water distribution pipework should be carefully designed to give minimum practical pressure drop. Consideration should be given to:

- Ensuring correct pipe size and hence water velocity (around 2 m/sec is desirable).
- Balancing pressure drop to avoid bottlenecks. In a well balanced system, head loss would be shared equally between the cooling tower (including static lift), the distribution pipework and the process/plant coolers.
- The detailing of fittings to minimise losses, e.g. the use of swept bends.
- Detailing in the vicinity of critical items, such as pumps, so as not to prejudice their performance and efficiency.

Manual design techniques can be used for small to medium-sized systems, but for larger networks, a range of proprietary software is available to perform the more complex calculations involved.

6. ACTION CHECKLIST

This checklist is a quick reference reminder of the measures covered in this Guide.

Stage 1 (Low Cost Measures)

- Review water costs, including any opportunities for a non-return to sewer rebate.
- Estimate how much electricity your cooling water system uses and how much this costs.
- If it costs more than £15,000/year, install a sub-meter to allow more detailed monitoring.
- Review point-of-use control to ensure:
  - cooling water is turned off when not required;
  - flows are regulated to prevent overcooling.
- Review pumping strategies to ensure:
  - pumps are turned off when not required;
  - only the minimum number of pumps are used to meet demand.
- If manual point-of-use or pump control strategies are proposed, ensure staff are adequately trained.
- Check non-return valves are installed and work properly on multiple pump arrangements.
- Ensure that proper water treatment and blowdown regimes are rigorously implemented.
- Ensure cooling tower sump heaters are effectively controlled.

Stage 2 (Higher Cost Projects)

- Consider fitting automatic devices to improve point-of-use control, for example:
  - solenoid valves to provide auto-isolation;
  - thermostatic controls to regulate flows.
- Consider automatic devices to improve pump control, for example:
  - sequence (step) control;
  - variable speed drives.
- Consider automatic devices to improve the control of cooling towers, for example:
  - thermostatic control of fans;
  - variable speed drives.
- When motors need replacing, specify high-efficiency types.
- Measure pump efficiency and refurbish/replace if necessary. Consider the use of low friction coatings.

Stage 3 (Strategic Issues)

- When cooling towers need replacement/refurbishment consider:
  - tower location;
  - high-efficiency packings;
  - high-efficiency mist eliminators;
  - spray distributors.
- When designing a new, or extended, cooling water system consider:
  - operating temperatures;
  - pipe network design;
  - Pinch technology to reduce cooling loads.

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

Further information

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Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.